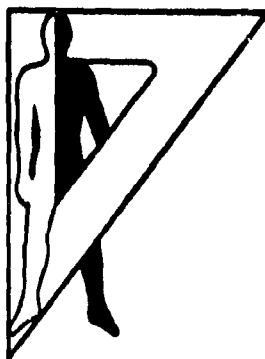


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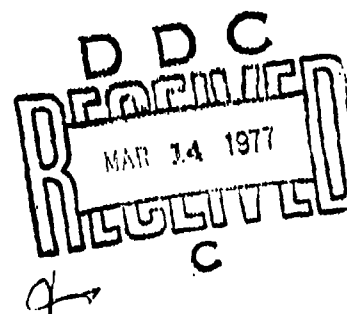
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Technical Memorandum 6-77

PILOTAGE NAVIGATION UTILIZING A NIGHT-VISION SYSTEM

Neil A. Johnson
Murray Foster, Jr.



February 1977
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Aberdeen Proving Ground, Maryland

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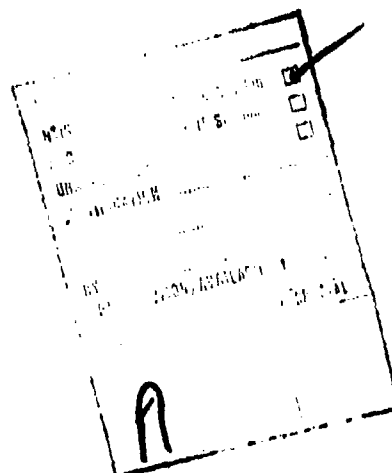
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February 1977



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PILOTAGE NAVIGATION UTILIZING A NIGHT-VISION SYSTEM

INTRODUCTION

The major focus of experimentation with night-vision systems has been on developing requirements for pilot flight aids and target-acquisition systems. Very little experimentation has addressed the specific problems of nap-of-the-earth (NOE) pilotage navigation using night-vision systems: What information is required to relate a displayed image of the terrain to a map, and direct a pilot over a given course to a specific objective?

The U. S. Army Combat Developments Experimentation Command (CDEC) did conduct one field test that collected limited data on pilotage navigation, entitled "Attack Helicopter - Clear Night Defense Phase I (USACDEC Experiment 43.7) (1)." Phase IIa of this experiment employed an unmodified AH-1G helicopter (i.e., without night-vision systems) to obtain baseline performance, which was compared to night-vision performance data measured with the COBRA OPTIC helicopter (test aircraft with forward-looking infrared equipment).

The results of the Phase IIa experiment showed that the COBRA OPTIC aircraft gave significantly better performance for both target acquisition and flight control at night. However, there was a problem in using the target-acquisition system for navigation. While this difficulty was not reflected in test data, the consensus of the aviators was that they had no confidence in their ability to perform night navigation with the target-acquisition system, because of its limited field of view ($15^{\circ} \times 20^{\circ}$). Scheduling did not permit further investigation of this problem.

Another investigation, the Advanced Scout Helicopter (ASH) Man-Machine Interface Analysis (2) conducted at the U. S. Army Human Engineering Laboratory (USAHEL), revealed gaps in the data about ability to use night-vision imagery for pilotage navigation.

Since the Advanced Attack Helicopter (AAH) and the ASH are to be equipped with a Target Acquisition/Designation System (TADS), it is assumed that this same subsystem will provide the night visual-navigation capability. It is also assumed that the display medium and the field of view for the navigation application will be subject to trade off constraints imposed by the basic TADS subsystem.

Thus it is necessary to systematically investigate the display parameters required for accurate navigation. The purpose of this report is to present data from the Joint Night Vision Laboratory and Human Engineering Laboratory Navigation Experiment, which was directed at determining how field of view and display medium affect a flight-crew member's ability to perform pilotage navigation with a night-vision system (forward-looking infrared). For the purpose of this experiment pilotage navigation was defined as the ability to navigate by correlating geographic landmarks with a hand-held map.

METHOD

Subjects

The subjects were all COBRA-qualified aviators assigned to the 6th Combat Brigade (Air Cavalry) at Fort Hood, TX. They ranged in age from 22 to 31, with a mean age of 27. Average flight experience for the six subjects was as follows: years rated, 4.5; rotary-wing experience, 1466 hours; NOE experience, 416 hours. All but two of the subjects were school trained in NOE flight and map interpretation.

Equipment

The test aircraft was an AH-1G helicopter with a turret-mounted FLIR system, helmet-mounted display (HMD), and a panel-mounted display (PMD). The FLIR system was chosen because it is a true night-vision system that can also be used during the daytime. The turret was 16 inches high and 13 inches in diameter; it could be slewed 90° left and right from center, and 32° up and down. The turret's elevation system used an internal mirror system. Activating a switch selected either of two fields of view. Changing the optics gave a third field of view.

This experiment used three fields of view: 15° vertical x 20° horizontal; 30° vertical x 40° horizontal; and 45° vertical x 60° horizontal. Based on these fields of view, the apparent magnifications at the subject's eye are given in Table 1.

TABLE 1
Apparent Magnification for Each Field of View

	Sensor	Helmet-Mounted Display	Panel-Mounted Display
Narrow	15°x20°	2X	1.2X
Medium	30°x40°	1X	.6X
Wide	45°x60°	.6X	.4X

The optics for the wide field of view could not be moved in elevation, and subjects reported this caused some difficulty in tracking certain checkpoints. The subjects' performance, however, indicated that this was not a major problem, as compared to the other FOV's.

The HMD is a monocular unit which receives its image through optics from a 1-inch CRT. The CRT and a small video amplifier are located on the helmet, while associated electronics are located in the pilot's night-vision-system power supply. The head-tracker linkage assembly consists of two parallel rails mounted longitudinally above and left of the user's head. This system slews the sensor in the direction the pilot's head turns. The weight it added to the user's head was less than one-half pound.

The PMD is an 875-line monitor with edge-lighted controls. This display is located in the top center of the instrument panel. The PMD has manual slewing controls to orient the sensor.

For this experiment the rear pilot's station was completely enclosed by a curtain and served as the subject's seat. A safety pilot who had full visual reference to the outside flew the aircraft from the front seat.

Data-recording equipment was mounted in the ammunition bay. Each flight was videotaped directly from the FLIR display, and communications were also recorded on the videotape.

Each flight was overflown by a UH-1M Chase Aircraft, which provided an airborne observation platform as well as a communications relay to the data van at the NVL helipad at Fort A. P. Hill, VA. The data van had full two-way communications facilities.

Logistics

The test used a range at Fort A. P. Hill, VA. For this test, NOE course number two was divided into two courses, each of which had an initial point (IP), six checkpoints (CP), and a release point (RP). The terrain in this geographic location is very low, rolling, and heavily wooded. Numerous streams and small ponds are scattered throughout the area. The test courses are cross-country; they do not follow any roads, but various roads and trails were used as checkpoints.

The NVL Support Branch provided the aircraft and all support and maintenance personnel. HEL arranged for the aviator subjects and provided the chief experimenter and data-reduction personnel. All operations were directed from the NVL compound at Fort A. P. Hill, VA.

Experimental Design

The experimental design incorporated three modes of viewing (naked eye, HMD, and PMD), three fields of view, and two NOE courses. Conditions were counterbalanced to control for practice effects and terrain variations, as shown in Appendix A.

Procedure

Each subject was given one week of training on the operation of the FLIR system with both HMD and PMD. The subjects were given the opportunity to navigate over courses and terrain similar to the actual test area. However, training was conducted on courses separate from the actual test courses. All subjects approached a learning asymptote at the end of the one-week training period.

Test trials were conducted during the second and third week. A typical test trial proceeded as follows.

Each subject navigator and pilot received a pre-mission briefing that discussed the course to be flown and the procedures to be followed. The navigator was issued a map which showed the courses to be flown in yellow. The test aircraft was piloted from the front seat by one of the two highly experienced safety pilots used in this experiment.

The navigator was seated in the rear seat, completely enclosed by a curtain, and he navigated solely by reference to the HMD or PMD and a hand-held map (except for naked-eye baseline trials).

Upon arrival at the IP, the pilot announced to the navigator that he was at the IP and on course. From that point on the navigator was required to identify all checkpoints and the RP. The safety pilot never aided the navigator unless he was completely disoriented or unable to identify a terrain feature. If the navigator missed a CP, he was allowed to continue a short distance to see if he realized his mistake and could reorient himself. If not, the safety pilot placed the aircraft back on course at the last known point. In many instances the navigator was able to instruct the pilot to backtrack, or hover and do a pedal turn, until he was able to identify his position. The CP's and RP's were scored as achieved if the navigator was within 100 meters of them. During the trial run the safety pilot maintained as low an altitude as he possibly could—and as fast an airspeed as safety and the navigator would allow.

For reasons of safety, all test trials were conducted during daylight hours. Since the FLIR system's amplifier can be saturated during daylight hours, all trials were conducted during the early part of the day. On any day that a reasonable image (i.e., sufficient detail by which to navigate) could not be achieved, test trials were not conducted.

The major dependent variables in this experiment were the number of missed CP's and RP's, the number of complete disorientations, and the time to complete the mission. During the initial feasibility study, it became evident that a number of other navigational factors could contribute to aborted missions. These factors include the number of backtracks to the last known CP, orientation stops, course deviations, missed landmarks and terrain features, and take overs by the safety pilot. Each of these variables is operationally defined in the Performance Measures section.

At the end of each day of trials, the subjects and safety pilots were debriefed informally. When all trials had been completed, there was a formal debriefing, and all responses to questions were tape recorded. The subjects were then released to their home unit.

RESULTS

The results were analyzed using analysis of variance where appropriate. Other data are presented as probabilities.

One performance measure considered important to mission success was time to complete the course. Each of the courses was approximately 8 kilometers long. Time to complete was calculated from the moment of crossing the IP to the moment of arriving over the RP. The analysis of variance is summarized in Table 2. The table shows there were no statistically significant differences between displays or between fields of view. However, there was a significant ($p < .06$) display \times FOV interaction. Figure 1 illustrates this time relationship graphically. A Tukey test (3) reveals that there were significant differences between the narrow and wide FOV for each display. The displays also gave much longer times than the baseline data, which were collected when the navigator used his naked eye to fly the courses. The next section discusses the implications of these findings.

TABLE 2

Analysis of Variance for Time to Complete Mission

Source	SS	df	MS	F	P
Subjects	97.64	5			
Display	8.50	1	8.5	.76	NS
FOV	216.94	2	108.47	2.45	NS
Display x FOV	193.11	2	96.55	3.87	<.06
Error (Disp)	55.65	5	11.13		
Error (FOV)	442.77	10	44.27		
Error (Disp x FOV)	249.14	10	24.91		
Total	1263.75	35			

Another major performance variable in this investigation is the likelihood of aborting a mission. Virtually every flight which utilized the FLIR system produced some combination of these nine events:

Performance Measures

Missed CP/RP—The subject did not recognize the reporting point or checkpoint during the flyover.

Backtrack—The safety pilot had to fly back on the same track until the subject was able to determine his position, either because the subject requested it or because the safety pilot felt it was obvious that the subject was completely disoriented.

Complete Disorientation—Subject was lost.

Orientation Stops—The subject requested a stop to insure that he was oriented correctly or to regain orientation. The safety pilot could initiate an orientation stop if he felt the subject was disoriented.

Course Deviations—The subject deviated from the planned course.

Turnaround (No backtrack)—The subject made a 180° pedal turn for orientation, initiated by either the subject or the safety pilot.

Help from Safety Pilot—The subject was lost, but was not aware that he was lost.

Missed Landmark/Terrain Feature—The subject did not see a landmark or terrain feature within the field of view.

Time to Complete—The total time between crossing the IP and crossing the RP.

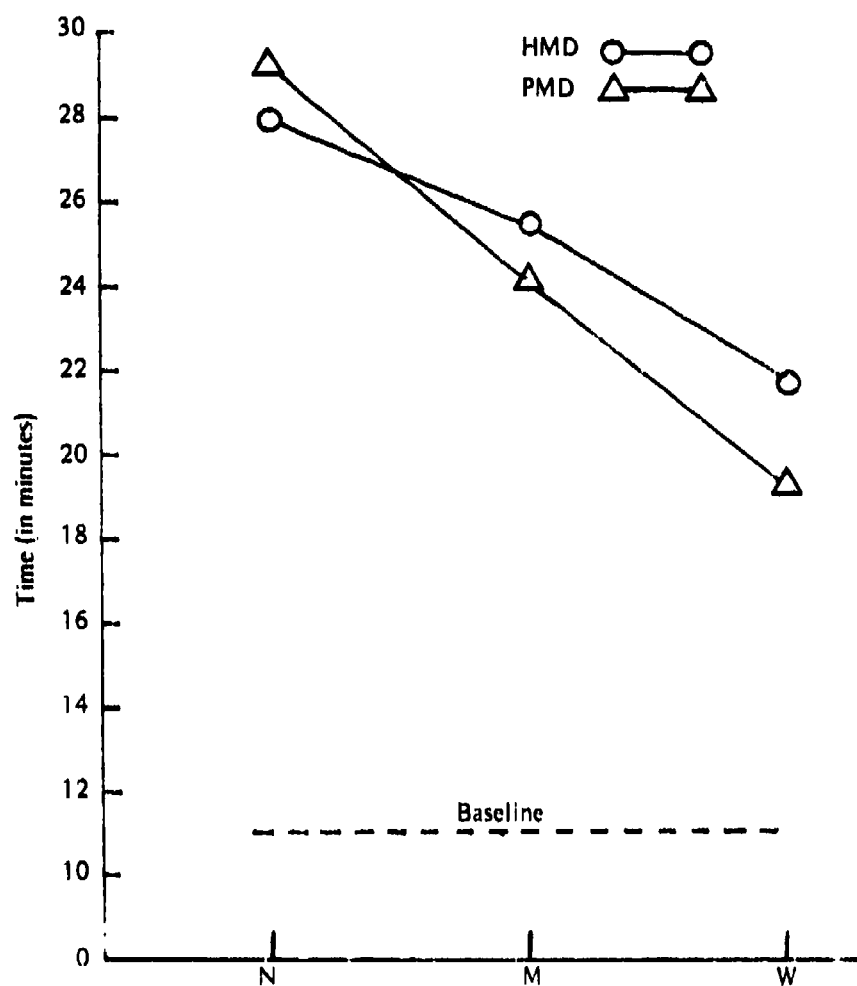


Figure 1. Mean completion time for type of display (HMD: Helmet-mounted display; PMD: Panel-mounted display) and size of visual field (N=15°x20°, M=30°x40°, W=45°x60°).

The reader will note, however, that some of these events have more serious consequences (greater weighting) than others, and would inevitably lead to an aborted mission. For this experiment, two of these scores (complete disorientation and help from the safety pilot) have been combined as a gross error measure, thus allowing some indication of the likelihood of mission abort. Table 3 summarizes an analysis of variance for the total errors of this type the navigators made under each condition of flight. A Tukey test reveals that there were significant differences between the wide field of view and the other two FOV's (medium and narrow). The subjects made significantly fewer errors with the wide FOV ($45^{\circ} \times 60^{\circ}$) than with the narrow FOV ($15^{\circ} \times 20^{\circ}$); this difference is significant at the .01 level. Between the wide and medium FOV ($30^{\circ} \times 40^{\circ}$), there were significantly fewer errors (.05 level) with the wide FOV. There was no significant difference between errors with the narrow and the medium FOV's.

TABLE 3
Analysis of Variance for Gross Errors Committed

Source	SS	df	MS	F	P
Subjects	214.56	5			
Display	5.44	1	5.44	1.03	
FOV	150.05	2	75.02	8.07	<.01
Display x FOV	5.05	2	2.52	<1	
Error Disp.	26.22	5	5.24		
Error FOV	92.95	10	9.29		
Error Disp. x FOV	89.29	10	8.92		
Total	583.56	35			

Dividing the total number of CP's and RP's that a subject could achieve by the total number of errors committed gives an approximation of the probability of mission abort (Figure 2). The baseline data is again notable, because its mission-abort probability is zero.

A further bit of data is worthy of consideration. Dividing the number of CP's identified correctly by the total number of CP's gives the probability of missing a CP (Figure 3). For this performance measure, the baseline data reflect a zero probability of missing a CP. Figure 3 shows that the probability of missing a CP is, in some cases, surprisingly low. The reader should not be misled, however, because the navigator could backtrack, spend time hovering, turn around, etc., and still achieve the CP according to the rules of the experiment. Under battlefield conditions the probabilities of aborting a mission or missing a CP could be expected to increase.

Finally, it is reasonable to ask, "Were the navigators taking full advantage of the sensor's slew capability, or did inadequate slewing cause the obtained differences between fields of view."
(2)

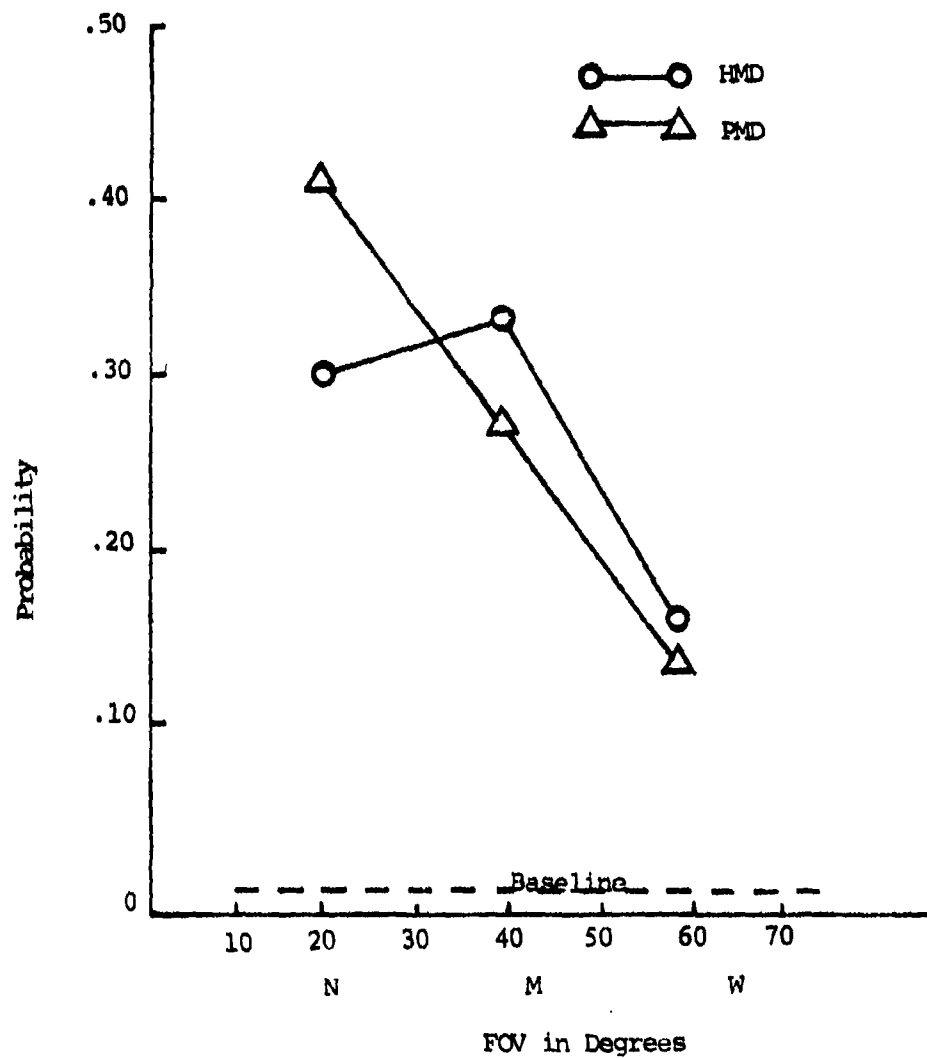


Figure 2. Probability of mission abort as a function of display type and field of view (N=15°x20°, M=30°x40°, W=45°x60°).

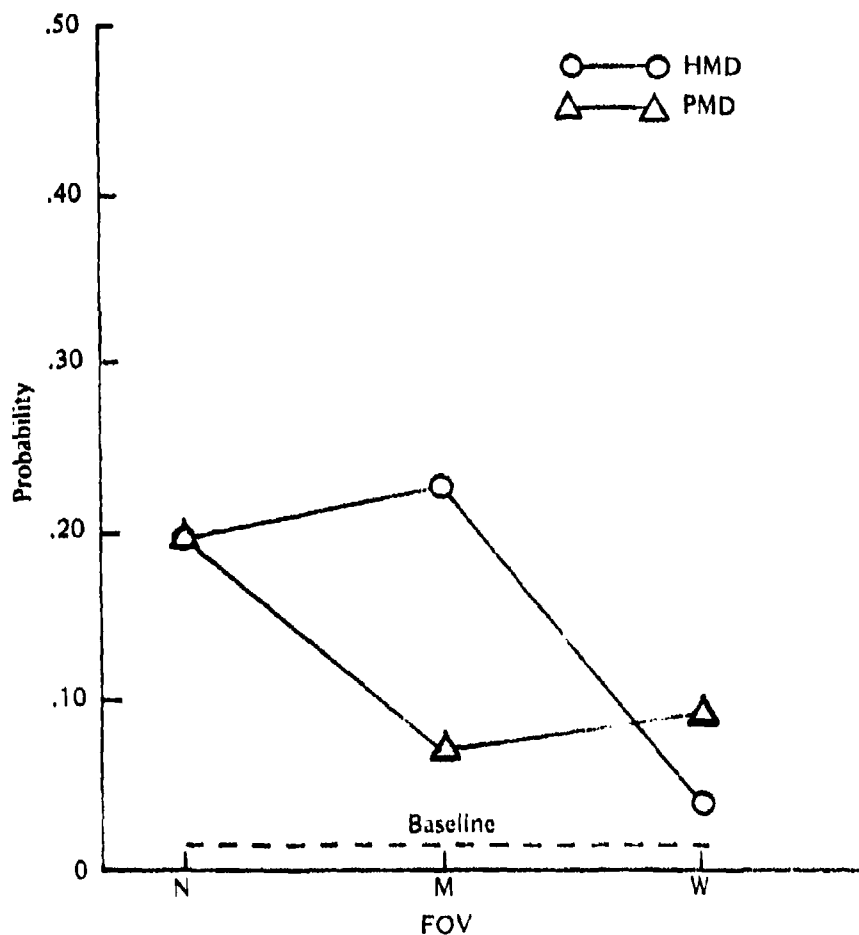


Figure 3. Probability of missing a CP.

The heading-reference symbol and the sensor-reference symbol on both the displays appear on all the videotapes of the trials. By placing a reference-scale overlay on the playback monitor, the number of sensor slews for each condition can be determined; it gives an indication of the relationship between sensor slewing, display, and field of view. Table 4 summarizes the analysis of variance for sensor slews under each condition.

TABLE 4
Analysis of Variance for Number of Sensor Slews

Source	SS	df	MS	F	P
Subjects	21,428	5			
Display	298,116	1	298,116	60.92	<.001
FOV	159,314	2	79,657	16.28	<.001
Display x FOV	31,657	2	15,828	3.23	<.1
Residual*	92,975	19	4,893		
Total	603,490	29			

*Pooled error term

The analysis indicates that there are significant differences between displays and between FOV's. The HMD was slewed considerably more than the PMD and, the narrower the FOV, the more slewing there was. The interaction between FOV's and displays, significant at the .10 level, indicates that the displays differ less in number of slews at the widest FOV than at the narrower FOV's. Figure 4 indicates the relationship between sensor slews, displays, and FOV.

DISCUSSION

Taken together, the data from this field test demonstrate that pilotage navigation using night-vision systems with restricted fields of view is a difficult task. Although the conditions of this test were not always optimum—at times the FLIR operated below specified performance—the test conditions were certainly not comparable to battle conditions. In other words, the data from this experiment can be interpreted as being neither a best case nor a worst case.

The data indicate that a wide FOV, on the order of 45° vertical x 60° horizontal, is more effective for NOE navigation purposes than narrower FOV's. Even when the navigator utilizes the slewing capability extensively, the narrow FOV does not provide adequate information for accurate pilotage navigation. The wide FOV used in this investigation would probably have been enhanced even more if it had incorporated an elevation function.

One critical area of this investigation is the time to complete the mission. Although the courses flown were only 8 kilometers long, nearly all flights took over 20 minutes to cover this distance. During these flights, the pilot spent considerable time hovering while the navigator oriented himself. During these flights, the power required left very little power margin, and excessive fuel was burned; thus it appears that longer missions would not be feasible. Hot, humid days and NOE altitudes complicate this problem further.

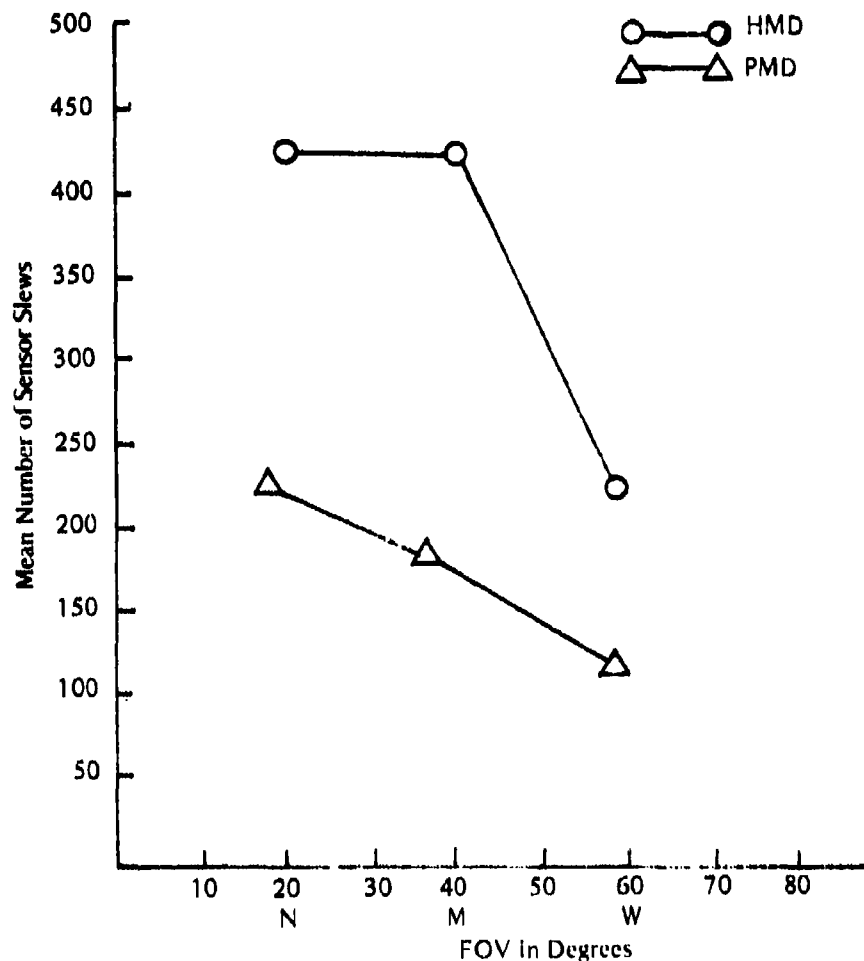


Figure 4. Number of sensor slews as a function of display type and field of view.

This test attempted to control for any aid the pilot (who was experienced on the NOE courses) might give the navigator. Consequently, communication between pilot and navigator was restricted as much as possible.

The navigator was forced to tell the pilot where and when to turn, stop, etc. A question may arise that this is not a realistic scenario, that the pilot would ordinarily give more information to the navigator. Field experience, however, indicates that the pilot's workload in flying over unfamiliar terrain at NOE altitudes is so heavy that he cannot give the navigator much help. Furthermore, the navigator in this experiment was operating at 100% workload, which prevented him from performing any other tasks except navigation.

The area of sensor-aided NOE navigation poses additional problems that are beyond the scope of the present investigation. The present investigation has demonstrated that a third FOV is needed for navigation, and it has shown that the FOV adopted for this purpose must be wider than 40° in the horizontal plane.

The authors believe that a systematic investigation of these problems should be undertaken and, in fact, the present field test has provided a baseline from which to proceed. The next phase should evaluate how adding a DOPPLER radar to the system affects pilotage-navigation performance. The aircraft development test activity is currently evaluating a DOPPLER radar coupled to a projected map display. ECOM will evaluate navigation with DOPPLER radar in early 1977. While previous studies did not have access to the recently released systematic approach outlined by McGrath (4) in a report entitled, "A Technical Approach to the Evaluation of Navigation Systems for Army Helicopters," future investigations would benefit considerably by adopting this approach. Hopefully, this type of systematic investigation will be undertaken in the near future.

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APPENDIX A

TESTING SEQUENCE FOR THE PILOTAGE NAVIGATION EXPERIMENT

Subject	Trial						
	1	2	3	4	5	6	7
1	PMD (N)	HMD (M)	HMD (N)	PMD (M)	PMD (W)	HMD (W)	B
2	HMD (M)	PMD (N)	PMD (M)	HMD (N)	HMD (W)	PMD (W)	B
3	HMD (W)	PMD (M)	PMD (W)	HMD (M)	HMD (N)	PMD (N)	B
4	PMD (M)	HMD (W)	HMD (M)	PMD (W)	PMD (N)	HMD (N)	B
5	HMD (N)	PMD (N)	HMD (W)	PMD (W)	PMD (M)	HMD (M)	B
6	PMD (N)	HMD (N)	PMD (W)	HMD (W)	HMD (M)	PMD (M)	B

Key to Conditions:

- N - Narrow field of view
- M - Medium field of view
- W - Wide field of view
- HMD - Helmet-mounted display
- PMD - Panel-mounted display
- B - Baseline

APPENDIX B

SAFETY-PILOT BRIEFING

1. Fly to IP, announce to subject that you are at IP and make sure he is oriented before you proceed.
2. For trial runs communication from the pilot to the subject should be only to acknowledge subject's input and ask for directions. For example, if subject says, "we should be coming to a crossroad", safety pilot should say, "Roger, tell me when we are there and which way you want me to go".
3. The procedure for a wrong turn or sudden disorientation should be to do a 180° turn and go back to the last known CP and proceed again.
4. The videotape should be left on at all times. It is very important that we have the information recorded during disorientation.
5. Whenever possible, the safety pilot should make gentle (i.e., not steep) turns because the latter has a tendency to wash out the video image.
6. Safety pilot should remind subject to instruct him on how fast or slow he wants to fly. Subjects will be briefed to fly as fast as they can navigate and/or you will let them.
7. Be careful not to anticipate the subject's response. In other words make the subject tell you when he is at a CP, crossroad, stream intersection, etc., and what he wants you to do. If you don't get specific instructions at one of these points, come to a hover and ask the subject.
8. Although we want the subject to direct the flight as much as possible, do not at any time sacrifice safety procedures.

APPENDIX C

SUBJECT (NAVIGATOR) BRIEFING

1. Before each trial that you fly, do a thorough map reconnaissance of the routes to be flown. Familiarize yourself with the CP's and prominent terrain features along the way.
2. As you proceed along a course make sure you adjust the image on the display to give you maximum resolution. Be aware that changing conditions require readjustment of the image.
3. You are responsible for telling the pilot when you are at a CP and also for telling him what you want to do next. For example, when approaching a crossroad you must acknowledge to the pilot that you see the crossroad and that you want him to turn a particular direction (left or right, etc.). Be specific and use standard NOE terminology to describe terrain features. You must constantly tell the pilot what you want him to do.
4. Take advantage of the slewing capability of the system. Many subjects forget to use it.
5. Take advantage of the polarity-switching capability of the system. This gives you comparisons for positive identification of terrain features and CP's.
6. If you become lost or disoriented tell the pilot and he will do a 180° turn and proceed to the last known CP.
7. You should tell the pilot to fly faster or slower as the need arises. You should fly these courses as fast as you can accurately navigate.